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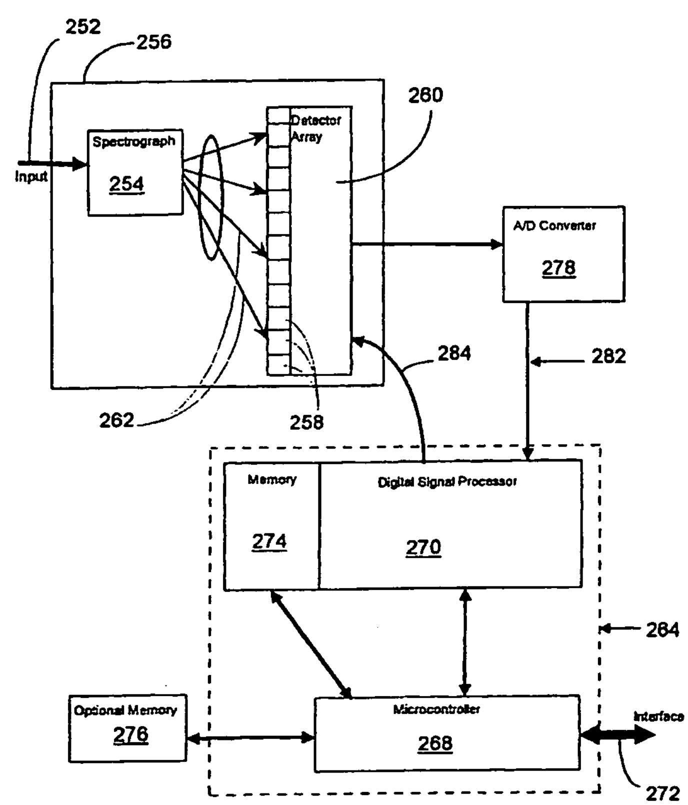
(54) Title: OPTICAL NETWORK MONITOR

(57) Abstract

An optical network monitor and a method for monitoring the optical signals of an optical network including a spectrograph (254) that includes a detector array (260), a processor (264) and output (272). The network monitor receives an optical input signal (252) which includes individual channels. The optical signal is transmitted onto the spectrograph which disperses the optical signal into the individual channels. The individual channels are directed onto the detector array so that the channels are spaced across the detector array. The detector array detects the channels in parallel and transmits to the processor channel parameter data which processes the parameter data through internal algorithms to produce the outputs.



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OPTICAL NETWORK MONITOR

Brief Description of the Invention

This invention relates generally to an optical network monitor, and more particularly to a network monitor wherein the network is a Dense Wavelength Division Multiplexing network.

Background of the Invention

Dense Wavelength Division Multiplexing (DWDM) is the accepted solution for increasing telecommunication network capacity, while controlling overall system cost. Currently, there are several manufacturers that offer multi-wavelength WDM systems using channel rates up to 10 GB/S. Some of these systems are scalable up to 400 GB/s at 0.4 nm channel spacing.

The wavelength allocations for the systems in deployment today all follow the ITU recommendation of 193.1 THz ± 100 GHz. Currently, manufacturers offer a variety of channel spacing such as 200 GHz (1.6 nm), 100 GHz (0.8 nm), and 50 GHz (0.4 nm).

The high bandwidth of the optical fiber, as well as the bandwidth of erbium-doped fiber amplifiers, enable DWDM. Amplifier bandwidth is usually the flat region of 1540 to 1560 nm, or about 1525 to 1565 nm for gain-flattened amplifiers. This demand for bandwidth has further stimulated research on extended-bandwidth amplifiers, which are reported to have bandwidths of about 1530 to 1610 nm.

Most of the installed fiber network lines assume a point to point link between sites. This architecture is being rapidly extended to include add/drop capability for channel wavelengths using switches and routers that control channel destination. Such

desired network flexibility requires monitoring for operation and management. For example, a change of the power of an added channel may degrade Signal to Noise Ratio (SNR) of other channels, or alternately, a rerouted wavelength may not have the needed SNR to carry traffic if injected into routes that do not have ample safety margins.

Furthermore, monitoring the status of DWDM channels has become a requirement to minimize network down time, as well as to initiate preventive measures, such as aging or drift of individual transmitters. Alternatively, environmental conditions or damage to the fiber cable may degrade some or all transmissions. Such a variety of events require the network manager to monitor all network-operating conditions simultaneously. Knowing the location and source of a fault goes a long way to minimizing repair time or the number of affected calls.

The most significant parameters that are required in channel monitoring are channel power, SNR and wavelength. Channel power and SNR are affected by the accumulation of insertion loss, polarization dependent loss (PDL), amplifier gain, and other effects, of the various in-line components in the network. Channel wavelength is driven by the transmitter's wavelength. If the wavelength drifts beyond its specifications, which are very tight for 50 GHz channel spacing, it contributes to cross talk and its failure, as well as neighboring channels.

There are other parameters that may be measured out in the field, such as cross talk and amplifier gain; however, the above three are the most important in a DWDM system. Other network requirements for optical monitoring are long operating lifetime, minimal servicing, low cost and integration into the network management system via the supervisory channel.

FIG. 1 shows a schematic of a DWDM network 110 including optical network monitors 112 for monitoring the status of all channels on the optical network 122. A transmitter node 114 transmits data at various wavelengths 116, 118 onto the optical network 122. An intermediate node or mid-node 124 may be positioned on the optical network 122 for adding or dropping data from the network 122. The network 122 terminates in a receiver node 126. It is very efficient to monitor the network at multiple nodes throughout the network to ensure accurate transmission of data. FIG. 1 shows three ONMs 112 for monitoring the network at various locations to ensure

accurate initial transmission, accurate adding or dropping of data and accurate receiving of data.

There are a variety of prior art approaches to spectral analysis, particularly as applied to DWM networks. Each has its own merits and shortcomings. These prior art approaches are summarized in FIGS. 2a-d.

- Rotating grating/fixed detector OSA, shown in FIG. 2a.

This configuration has a rotating grating, which allows for wide spectral range (600 nm to 1700 nm). As shown in FIG. 2a, the approach also accommodates a double-pass over the grating, which gives the signal dynamic range of a double monochromator (-65 dB at 1550 nm) with the sensitivity of a single monochromator (-90 dBm at 1550 nm), as well as polarization insensitivity. However, moving parts, as in the direct-drive motor system for grating tuning, generally make the mechanism sensitive to vibrations and shock. In addition, an internal adsorption cell helps in wavelength calibration. The majority of units in laboratories today utilize this configuration.

- Fixed grating/scanned detector OSA, shown in FIG. 2b.

In these OSAs the detector is scanned against a stationary grating. This reduces the number of moving parts, making it less prone to shock and motion; however, at the expense of a reduced wavelength range of 1525 to 1570 nm. The moving detector also slows the data acquisition and integration cycles. Typical resolution bandwidth of 0.1 to 0.5 nm, amplitude measurement accuracy of <0.8dB and small size make it convenient for characterizing WDM networks.

- Scanning Michelson Wavelength Meter, shown in FIG. 2c.

By counting the number of fringes as one arm of a Michelson interferometer is extended, one can measure the wavelength to a very high degree of accuracy. In the case of multiple wavelengths, counting fringes is insufficient to extract

their spectral profile. However, by measuring the amplitude of these fringes as the interferometer arm is extended, one can calculate the full spectrum of the input by performing a fast Fourier transform (FFT) calculation of these amplitudes.

This approach has the advantage of wide wavelength range (700 to 1650 nm) and wavelength accuracy of 10^{-2} to 10^{-4} nm for a single input wavelength, as well as 0.16 nm resolvable separation between input lines and power measuring accuracy of <1dB for multiple input wavelengths. The response time of the instrument, however, is reduced due to the combination of a scanning mechanism, integration time and FFT analysis.

- Scanning Fabry-Perot Interferometer (FPI), shown in FIG. 2d.

An FPI is composed of two parallel and closely spaced (30 to 50 μm) mirrors, separated by a piezoelectric (PZT) spacer. By applying a voltage to the PZT, the FPI mirror separation changes, allowing light to be transmitted through it if mirror spacing is a multiple of half wavelength of the input. However, PZTs are inherently prone to drift causing these peaks to also drift. To account for drift, FPIs require an additional independent reference for wavelength calibration such as an internal absorption cell. Alternatively, an external capacitor may be added as shown in FIG. 2d for mirror spacing measurement.

This capacitive micrometry approach, in combination with a high resolution FPI, can be used to produce a compact, solid state and board mountable device, having no moving parts. The spectral transmission characteristic of FPIs has, however, a limited rejection for wavelengths adjacent to the peak, which limits the dynamic range and SNR measurements. To improve isolation better than 25dB at 0.8 nm (with spectral range of 40 nm), the FPI requires Finesse values >350, where Finesse = spectral range/resolution, or a multi-pass configuration to improve rejection. The wavelength spectrum is developed by scanning the mirrors and averaging over the FPI spectral range.

All the technologies discussed above process channels serially with an internal wavelength scan. None of the above described systems suggest how to implement a solid state design without increasing the response time of the device or limiting the wavelength range monitored by the device, nor how to process the channels of the signal in parallel to provide simultaneous processing of the channels. A network monitor and method of monitoring an optical network implementing a solid state design which allows parallel processing of the channels of the optical signal suitable as a network element and as a network service instrument for debugging and installation has not been taught, nor has such a device been successfully commercialized.

Summary of the Invention

It is an object of the present invention to provide the ability to simultaneously process optical channels dispersed from an optical signal in parallel.

It is another object of the present invention to provide a device which has a solid state design with no moving parts.

It is another object of the present invention to be suitable as a network element and as a network service instrument for debugging and installation.

It is final object of the present invention to provide fast on-board analysis and provisioning for alarm reporting.

The optical network monitor of the present invention includes a spectrograph and a method for monitoring an optical signal on an optical network. The optical network monitor includes a spectrograph which includes a detector array, a processor and generates an output representative of the signal. The network monitor receives the optical signal and transmits the signal onto the spectrograph which disperses the optical signal into individual channels. The individual channels are further directed onto the detector array such that the channels are spaced across the detector array. The detector array detects the channels in parallel and generates channel parameter data. The channel parameter data is transmitted to the processor which processes the parameter data through internal algorithms to produce the output.

The spectrograph includes a means for collimating the optical signal. The collimated signal is directed onto a means for dispersing the collimated signal into the

individual channels. The individual channels are directed to a means for focusing the dispersed channels onto the detector array.

Brief Description of the Drawings

The foregoing will be better understood from the following description when read in conjunction with the accompanying drawings in which:

Figure 1 is a schematic diagram of a DWDM optical network including optical network monitors.

Figure 2 is a schematic diagram of the prior art network monitors.

Figure 3 is a schematic diagram of the optical network monitor including the spectrograph and the processor.

Figure 4 is one embodiment of an enlarged schematic of the spectrograph of Figure 3, showing the optical configuration and the linear array.

Figure 5 is another embodiment of an enlarged schematic of the spectrograph of Figure 3, showing the half-wave plate and the focusing lens.

Figure 6 is a schematic diagram of the dispersion of the optical input signal into individual channels.

Figure 7 is a schematic diagram of the optical network monitor including the processor.

Figure 8 is a block diagram of the conversion of element voltage into signal parameters.

Figure 9 is a flow diagram of the modeling of the dark current and removing the dark current from the output.

Figure 10 is a graphical representation of the fit-curve for the dark current calibration.

Figure 11 is a flow diagram for the calibration method of the network monitor.

Figure 12 is a schematic of the method of performing the power and wavelength calibration.

Figure 13 is a schematic of the automation of the calibration method shown in Figures 11 and 12, utilizing a computer.

Figure 14 is a schematic diagram of the implementation of the network monitor in an intermediate node.

Description of the Preferred Embodiments

The present invention is directed to providing an optical spectrometer or optical network monitor that examines the spectral content of a signal from an optical fiber and relays the information to operators of optical networks or to other interested parties. More preferably, the present invention is designed to examine the spectral content of DWDM networks. The input to the spectrometer is usually a tap off a fiber optical communication line that is carrying multiple channels, each at designated wavelengths. The output of the spectrometer includes data arrays that define the channels present and also includes measurements and calculations that are related to channel parameters.

The network monitor configuration is based on the combination of an input fiber, grating, mirrors, and a linear detector array in a solid state module that has no moving parts. This optical module is coupled to a processor card that processes the information using internal algorithms particular to the market of interest. The preferred design can be further customized to the DWDM communication market such that the spectral profile is examined for channels present in a narrow wavelength range in the telecommunication window which can include the range from approximately 1300 nm to 1600 nm. A more preferred design is for channels present in a narrow wavelength range around the 1550 nm telecommunication window, a particularly preferred design is for channels present in a narrow range 1525 to 1565 nm. The present invention can be also configured to operate with other telecommunication bands, including but not limited to, the 1565 nm to 1600 nm band, and the 1300 nm band, more preferably 1290 to 1380.

FIG. 3 shows a block diagram configuration of an optical network monitor (ONM) 112, FIG. 1, implemented in accordance with the present invention. It has an input fiber 142, which couples input signal 143 to the ONM, a spectrograph 144 including internal optical configuration 145 and a detector array 146, and a processor card 147. The internal optical configuration 145 of the spectrograph 144 separates the input signal 143 wavelengths across the detector array pixels or elements 152 of the detector array 146, such that each element 152 receives a particular wavelength of light or range of wavelengths 149. The measured power levels for the different wavelengths from the detector array 146 represent the

spectral profile of the input signal 143. The power levels of wavelengths 149 are then sampled and routed to the processor card 147 that digitizes, conditions and calibrates the measurements. The processor card 147 can also report alarms if certain conditions are or are not met. The output 154 of the ONM 112 is a sequence of data points that represents the spectral profile of the input signal 143 and other information of use to the network operators. For example, the ONM 112 can supply automatic channel recognition, its wavelength, optical power and signal to noise ratio.

The current invention replaces scanning mechanisms of prior art with non-moving solid state components to generate major advantages to the communications market. The dispersion of optical channels on the detector array 146 effectively allows for parallel optical processing of all wavelengths 149 present. This speeds up data acquisition and decreases alarm latency appreciably. This also allows for instruments to be installed in the field as intermediate or mid-nodes with minimal service requirements, which enables closed-loop system operation and signal routing and decreases network down-time.

If one or several channels experience drift of their optical properties, such as power, wavelength and signal to noise ratio, the optical monitor instrument measures this change and reports it as data and/or alarm to the network operator for appropriate action.

Because the ONM of the present invention employs solid state construction, the embodiment of FIG. 3 is suitable as a deployable instrument throughout the network because it has no moving parts that may be prone to drift with shock or temperature cycling or simply wear out with age, thereby requiring periodic calibration. One of the most significant attribute of the present invention is the ability to simultaneously process optical channels in parallel, without a scanning mechanism, which speeds up data acquisition and alarm reporting considerably. In contrast, all the technologies discussed above process channels serially with an internal wavelength scan. Furthermore, the present invention is suitable as a network element and as a network service instrument for debugging and installation.

Referring to FIG. 4, there is shown one embodiment of the internal configuration of the spectrograph 144. The spectrograph 144 is composed of an

input fiber 160, a first mirror 162, a second mirror 164, grating 166 and InGaAs linear detector array 168. The design is configured to produce a dispersion of channels 170 of the input light 172 of about 1530 to 1560 nm across the detector array 168. Therefore, each channel 170 is allocated a certain number of detector elements 174, where channel parameter data which can include optical power is measured simultaneously for all channels 170. In addition, the location of the peaks for each channel 170 also defines accurately the wavelength of each channel 170. SNR is simply the ratio of power intensities measured by different elements 174.

The illustrated configuration of the spectroscope in FIG. 4 can provide wavelength resolution of <0.3 nm and amplitude measuring accuracy of < 1 dB. The mirrors 162, 164, grating 166 and detector array 168 are configurable so the channels 170 are linearly dispersed across the detector array 168, which allows the channel characteristics to be determined for the maximum number of channels 170. In such a configuration, the maximum number of channels 170 that can be monitored is only limited by the detector's resolution (i.e., each channel 170 must be focused on at least one detector element 174). A suitable detector that can be implemented within the present invention is an InGaAs linear detector array, manufactured by EG&G of Vaudreuil, Quebec, Canada, or Sensors Unlimited of Princeton, New Jersey.

FIG. 5 shows a more preferred embodiment of the spectrograph 144. The spectrograph 144 of the ONM is designed as a high resolution Optical Spectrum Analyzer (OSA). As shown in FIG. 5, the spectrograph 144 includes an input single-mode fiber 200 and collimating lens 204. The combination of the fiber 200 and the collimating lens 204 combined to form an optical collimator 206 that collimates the input signal light 202 exiting the fiber 200. The collimating lens 204 may be replaced by other optical elements that collimates a diverging beam, such as mirrors or diffractive elements. In the embodiment shown in FIG. 5, the ONM was designed to be utilized with wavelengths of the telecommunications band of approximately 1515 to 1580 nm or particularly preferred 1525 to 1565 nm, however, the design is not limited to the telecommunication bandwidth and can be adjusted to address other bandwidths of interest. The spectrograph 144 further incorporates a first grating 208 and a second grating 210 for dispersing the input

signal 202 into dispersed channels. Collimated light 211 that is collimated by the collimator 206 is reflected by the first grating 208 producing a dispersed beam 212. The dispersed beam 212 passes through a half-wave plate 214, producing a polarized beam 216 that reflects off the second grating 210, producing the dispersed channels 216. The dispersed channels 216 are reflected towards a focusing lens 218. The focusing lens 218 produces a focused beam 222. The embodiment of the spectrograph shown in FIG. 5, including the grating choice and angle of incidence, produces the required dispersion and resolution that is applicable to the fiber optic telecommunications industry, which is to resolve 0.4 nm channel spacing and a wavelength band of approximately 1530 to 1560 nm. The focused beam 222 is focused onto a linear detector array 224. The present invention incorporates a liner InGaAs array 224 used for this ONM application which can include 256 elements (not shown), spaced at 50 um, thus having a length of 12.8 mm. Other linear arrays may be used to implement the present invention without departing from the inventive aspect of the invention described. A common wavelength range of interest is 32 nm. Therefore, the dispersion of interest is approximately 2.5 nm per mm at a detector array plane 226, or 0.125 nm per element (not shown).

Other aspects of the optical design of the spectrograph 144 shown in FIG. 5 is a flat field response 225 at the detector plane 226, reduced aberrations is achieved through the reduced aberrations of the optical elements 204, 208, 210, 214, and 218. Small spot size at the detector plane compared to the width of each pixel element is achieved through reduced aberrations, as well as keeping the beam 216 large enough such that the diffraction limited spot at the detector plane 226 is also small compared to the width of each pixel element. Reduced power sensitivity along the height of each pixel is achieved by the combination of stiffening the optical assembly 145 and/or by
increasing the spot size on the vertical dimension as compared with the pixel height. Stray light is reduced by adding anti-reflection coatings to the optics and by adding baffles and light masks. Compact size provides for reduced cost, weight, footprint and ease of implementation.

The half-wave plate 214 is incorporated to reduce the polarization dependent losses (PDL) for the instrument. The function of the half-wave plate 214 is to

reverse the vertical and horizontal polarization states of the input signal light 202 before the second grating 210. This will equalize the combined losses of the two polarization states after reflecting off the first grating 208, passing through the plate 214 and reflecting off the second grating 210. Minimizing PDL can also be accomplished by using gratings that have similar reflectivities for the vertical and horizontal states of polarizations, such as holographic gratings with controlled emulsion depths, thereby eliminating plate 214.

The dispersed channels 216 are focused by the focusing lens 218 onto the linear detector array 224. The focusing lens 218 can be a spherical or cylindrical lens or any other optical focusing elements, such as mirrors, and may incorporate aberration corrections. As the wavelength of the input signal light 202 exiting the fiber 200 changes, the focused beam 222 moves across the elements 236 of array 224. FIG. 6 shows a representation of the input signal 202 being reflected off a grating 232, through a focusing lens 234 and dispersed across the detector array 224. An input signal 202 having a wavelength of 1528 nm would send focused beam 222a to a first end 228 of the detector array 224, while an input signal 202 having a wavelength of 1560 nm would send focused beam 222b to a second end 230 of the detector array 224.

Internal algorithms utilizing an invoked calibration process, which is described in more detail below, converts the energy received by each element 236 from the focused beam 222 to a calibrated power level that correspond to the particular wavelength of light emitted by the fiber 200.

The mechanical aspect of the spectrograph 144 design incorporates low cost modular component adjustment, stiffening agents, light baffles, stray light reduction, thermal sensitivity reduction, and compact size.

FIG. 7 Shows a method of analyzing the data encoded within the input signal light 252 directed onto the optical configuration 254 of the spectrograph 256 and dispersed onto the elements 258 of the detector array 260 involves clocking the data out of the detector array 260 and processing it. A block diagram of this method is shown in FIG. 7. An on board microprocessor/controller 264, is coupled to the spectrograph 256, which is similar to the spectrograph depicted in FIG. 5 or 6. The microprocessor/controller 264 controls the timing and thermoelectric control (TEC)

284 of the detector array 260. The timing controls the integration time of the detector array 260 and clocking the data, while the TEC control maintains temperature regulation of the detector array 260 at a constant temperature. The TEC control enables the reduction of background noise at a range of operating temperatures.

The microprocessor/controller 264 can be a single processor or a dual micro-controller 268 and Digital Signal Processor (DSP) 270 as shown in FIG. 7. The DSP 270 is used for timing and TEC control, as well as data calibration and processing. The microcontroller 268 is used for a fast communication interface 272 to the outside world to report alarm status and measurement data. Coupled between the detector array 260 and microprocessor/controller 264 is the fast high-resolution analog to digital converter 278 that converts the analog data that is clocked out of the detector array 260 from an analog domain to digital domain and becomes the digital input data 282 to the microprocessor/controller 264. Also included within the ONM of the present invention shown in FIG. 7 is a digital signal processor memory 274, and an optional second memory 276 which is external to the microprocessor/controller 264. The DSP memory 274 is directly coupled to the DSP 270 and the optional memory 276 is coupled to the microcontroller 268. Both memories 274, and 276 are utilized during calibration and conversion of the data which is described more fully below.

Collected spectral data and alarm status information is stored in memory 274 and 276. The memory units 274 and 276 can also house the control program and internal algorithms that run the ONM which is described in more detail below. The memory 274 and 276 also store TEC control programs and any other routines that support the ONM operation and control.

FIG. 8 shows a flow-chart of the computer program or method of implementing the internal algorithms as discussed above that is utilized by the microprocessor/controller 264 to control the measurement data. The method starts by resetting the onboard electronic components and setting up default channel configuration and alarm thresholds 310. Channel configuration, as defined by the International Telecommunication Union (ITU), is typically 200, 100 or 50 GHz

channel spacing. This corresponds to approximately 1.6, 0.8 or 0.4 nm channel spacing respectively.

The DSP 270 shown in FIG. 7 starts with a default array integration time 312. This integration time is later adjusted 338 to expand the dynamic range for the ONM. The DSP 270 then prompts the detector array 260 to integrate 314 the wavelengths 262 being directed onto each element 258 of the detector array 260. The DSP 270 then prompts the detector array 260 to sample 316 the element voltage and clock the data out 318 to the analog to digital converter 278, which converts it to the digital domain 322. The process of 314 to 322 is repeated more than once and averaged 324 to reduce noise fluctuations. More preferably, the process of 314 to 322 is repeated at least 10 times and particularly preferred the process is repeated at least 32 times.

The method that control the measurement data continues with the removal of dark current or the background noise 328 which is described in more detail below. The output is then calibrated 332. Several calibration tables are stored on the ONM that are used with the internal algorithms for converting the output voltage of the elements 258 to a calibrated measurement 332. Once the output is calibrated, the internal algorithms are used to calculate 334 the channel power, wavelength and signal to noise ratio (SNR):

- Array element voltage measurement is converted to power for all elements. This is performed for a set calibration aperture. Since each element is roughly 0.125 nm wide, a 0.1 nm calibration aperture is used. Other calibration apertures such as 0.2 or .5 nm can be used.

- Channel spacing and channel boundaries are defined.

- Find the peaks in element power levels (A_n).

- Channel power $P_n = A_{n-1} + A_n + A_{n+1}$, or can be the sum of powers of several elements.

Noise Power is either the power level at the boundary or the minimum power level between two channels. Let noise at channel boundaries be N_{n-1} and N_{n+1} for the values at the short and long wavelength sides. Channel SNR(short) = P_n / N_{n-1} , and SNR(long) = P_n / N_{n+1} . An average SNR can also be calculated as SNR = $2P_n / (N_{n+1} + N_{n-1})$.

- Channel center wavelength is then calculated. One method of calculating the center wavelength is: Wavelength Center = (sum of (Element Power A_m * Center Wavelength of Element m), m=n-1, n, n+1)/(Channel Power P_n). Second-order correction (SOC) can be added to this equation to improve its accuracy, where SOC = a*delta*(B_m - B_{m-1} / 2 - B_{m+1} / 2), a is a constant defined experimentally, delta is element spacing in nm, and B_n = square root ($2A_n$). Other methods for calculating wavelength center can be employed as are know in the art.

The ONM uses this calibration table to scale the array measurements 332 and 334. The measurements are stored to memory 336 for historical evaluation. The memory used to store the measurements can include, but is not limited to, memory 274 and 276 (FIG. 7), or a memory external to the ONM (not shown). These measurements can be used for historical evaluation to compare results over prolonged periods of time, including several hours, days or even weeks. Alarm conditions are verified by calculating channel parameters 334 and comparing with stored alarm thresholds 342 for the network. A minor or major alarm is issued 342 depending on which threshold is violated. This alarm is reported via the communication ports 344. Alternately, alarm reporting and all other forms of communications may be performed via a telemetry channel or via an available Ethernet port, or through other means of communication know in the art.

FIG. 9 shows a method for modeling the dark current to be used to remove the dark current from the measurement data. First the dark current for all the elements is measured 360 for the range of integration time of interest. A best-fit curve or line is then generated 362 to match the test data for each element 258.

FIG. 10 show a best-fit curve or line 392 matching the test data 394 for each element 258 and the axial intercept 396. As shown in FIG. 9, the behavior for dark current for each element 258 is then modeled by a curve or line 364 and is then saved 366 onboard the ONM for background noise reduction. For a given integration time, the dark current is calculated 368 by using the stored model 366, for example, the slope and axis intercept 396 of a straight line fit. Dark current data is then removed from the averaged output 370.

A flow chart of the calibration method is shown in FIG. 11. Dark current calibration 410, described above and shown in FIGS. 9 and 10, is performed first. The calculated parameters that model the dark current can include such parameters as slope and intercept numbers for a straight-line fit or a set of numbers for a curve fit. Optical power and wavelength calibration 412 is then generated. The dark current model, the power and the wavelength calibrations are then downloaded 414 to the ONM.

The internal algorithms utilizing the dark current calibration step 410 allows the ONM of the present invention to calculate dark current for any integration time, and to deduct that amount from the element voltage, which increases the dynamic sensitivity for the instrument significantly, as well as increases the element voltage measurement accuracy by operating within the linear measurement range. An alternative embodiment to the storage of the dark current model is to require the ONM to store large amounts of data for all possible operating integration times, or limit the integration times to only specific values.

Optical power and wavelength calibration step 412 is then performed. FIG. 12 shows a method for accomplishing the power and wavelength calibration. A light source 422 projects light across all array elements 424 of the linear detector array 426 of the ONM 112. A comparison or calibration is performed with a reference optical and wavelength meter or optical spectrum analyzer 428 through a computer 430 or other means for performing the calibration. This calibration generates a table that maps element voltage and element sequence number to optical power and wavelength. This defines the boundaries and centers for the array elements 426, as well as the output generated for any integration time. Such a table is then downloaded 414 to the ONM.

FIG. 13 shows a block diagram for the automation of the calibration method described above and shown in FIGS. 11 and 12, by using a computer program 442 stored in memory 440 and accessed by a processor 445 of a computer 444, and a combination of a light source 452, an ONM 456 and at least one of an optical power meter 454, a wavelength meter 456, or an optical spectrum analyzer 460 coupled to the computer 444 through a bus 461. This calibration process is typically performed whenever there is a change in array or array voltage bias, change in optical alignment or gain change of the instrument.

Referring to FIG. 14, there is shown a block diagram of an intermediate node 480 tapped to an optical communication network 482 implementing an ONM 484 of the present invention. A first tap 486 and a second tap 487 on the network 482 are coupled to a transceiver 488 which receives or transmits optical signal onto the network 482 through the WDMs or taps 486 or 487. A site controller 490 is coupled to the transceiver and directs the transceiver 488 to received or transmit data. When the site controller 490 directs the transceiver 488 to receive data, the data is transmitted to the ONM 484 of the present invention for monitoring. The ONM 484 processes the optical signal as described above and generates an output of the optical signal's profile parameters. The transceiver 488 receives the output from the ONM 484 and communicates the output onto the network 482 to be received by a systems administrator or other interested party. The intermediate node 480 can also be coupled to a local display module 492 for viewing of the ONM output. The intermediate node 480 can be controlled from a remote location utilizing the network 482 directing the site controller 490. The intermediate node 480 can also be controlled by a direct input at the intermediate node location. In addition, an Ethernet port 494 on the site controller 490 or an Ethernet port 496 on the ONM 484 can be used to communicate data and control the intermediate node directly, without using the telemetry channel described by taps 486 and 487 and transceiver 484.

WHAT IS CLAIMED:

1. An optical network monitor for monitoring optical signals on an optical network, comprising:

a spectrograph for receiving an optical input signal including individual channels, and dispersing the optical signal into the individual channels;

a detector array including a plurality of detector elements positioned so that the channels are spaced across the detector array, whereby the detector array detects the channels in parallel and creates a detector output signal representative of the intensity of the optical signal for each channel.

2. The optical network monitor as claimed in Claim 1, wherein:

the detector array simultaneously detects the channels in parallel.

3. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph include at least one grating configured to disperse the optical signal into individual channels and onto the detector array.

4. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph including the detector array are in a solid state module which has no moving parts and secured in a fixed position.

5. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph disperses the optical signal into individual channels onto the detector array so that the channels are spaced across the detector array in such a way that elements of the detector array receive a range of channels.

6. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph disperses the optical input signal into channels about between 1525 nm and 1565 nm.

7. The optical network monitor as claimed in Claim 1, which additionally includes a processing means for processing the detector output signal through internal algorithms to produce an output.

8. The optical network monitor as claimed in Claim 7, wherein:
the processing means includes a digital signal processor and a microcontroller.

9. The optical network monitor as claimed in Claim 7, wherein:
the processing means includes internal memory.

10. The optical network monitor as claimed in Claim 7, wherein:
the network monitor includes memory external to the processing means and accessed by a microcontroller.

11. The optical network monitor as claimed in Claim 7, wherein:
the network monitor includes memory external to the processing means and accessed by the processing means.

12. The optical network monitor as claimed in Claim 7, wherein:
the internal algorithms include means for calibrating the outputs.

13. The optical network monitor as claimed in Claim 12, wherein:
the means for calibrating the output includes removal of dark current from an element voltage.

14. The optical network monitor as claimed in Claim 12, wherein:
the means for calibrating the output includes adjustment of an element voltage through a calibration table which includes a map of element voltage and element sequence number to optical power and wavelength.

15. The optical network monitor as claimed in Claim 1, wherein:

the detector output signal is an element voltage sampled from at least one element of the detector array.

16. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph including the optical input signal directed onto a means for collimating the signal which produces a collimated signal, the collimated signal directed onto a means for dispersing the collimated signal into dispersed channels, the dispersed channels are directed onto a means for focusing the dispersed channels across a linear detector array.

17. The optical network monitor as claimed in Claim 1, wherein:

the spectrograph including the optical signal directed through a collimator lens onto a grating which produces dispersed channels, the dispersed channels are dispersed across a linear detector array.

18. An optical network monitor for monitoring optical signals, comprising:

a spectrograph for receiving an optical input signal including individual wavelengths, and dispersing the optical signal into the individual wavelengths; and

a detector array including a plurality of detector elements positioned so that the wavelengths are spaced across the detector array, whereby the detector array detects the wavelengths in parallel and creates a detector output signal representative of the intensity of the optical signal for the individual wavelengths.

19. The optical network monitor as claimed in Claim 18, wherein:

the spectrograph disperses the optical signal into wavelengths onto the detector array so that the wavelengths are spaced across the detector array in such a way that each element of the detector array receives a range of wavelengths.

20. The optical network monitor as claimed in Claim 19, wherein:

the wavelengths are spaced across the detector array in such a way that each element of the detector array receives a single wavelength.

21. The optical network monitor as claimed in Claim 19, wherein:
the range of wavelengths are limited between about 1290 nm to 1610 nm.

22. The optical network monitor as claimed in Claim 19, wherein:
the range of wavelengths are limited between about 1560 nm to 1600 nm.

23. The optical network monitor as claimed in Claim 19, which additionally includes a processing means for processing the detector output signal through internal algorithms to produce an output.

24. The optical network monitor as claimed in Claim 23, wherein:
the processing means includes a processor card to process the detector output through the internal algorithms

25. The optical network monitor as claimed in Claim 24, wherein:
the internal algorithms digitize, condition and calibrate the measurements to produce the output.

26. The optical network monitor as claimed in Claim 23, wherein:
the output includes a sequence of data points that represent the spectral profile of the optical signal.

27. The optical network monitor as claimed in Claim 23, wherein:
the output includes an alarm if certain predetermined conditions are met.

28. A method for examining the spectral content of an optical signal, comprising:
projecting the optical signal onto a spectrograph including at least one grating;
separating the optical signal into ranges of wavelengths across a detector array;
integrating the wavelengths creating an element voltage for each element;

processing the element voltage through a processor utilizing internal algorithms; and

generating an output of the optical signal's profile parameters.

29. The method for examining the spectral content of an optical signal as claimed in Claim 28, wherein:

creating the element voltage for each element including integrating the wavelengths across the detector array, sampling the integrated wavelengths creating the element voltage and clocking the element voltage out of the detector array.

30. The method for examining the spectral content of an optical signal as claimed in Claim 29, wherein:

processing the element voltage including reducing noise fluctuation by generating an average of the element voltage.

31. The method for examining the spectral content of an optical signal as claimed in Claim 30, wherein:

generating an average of the element voltage by integrating, sampling and converting from analog to digital the wavelengths dispersed across the detector array at least twice and averaging the element voltage.

32. The method for examining the spectral content of an optical signal as claimed in Claim 28, wherein:

processing the element voltage including removing dark noise.

33. The method for examining the spectral content of an optical signal as claimed in Claim 32, wherein:

removing the dark noise by calculating dark current utilizing stored parameters that model the dark current behavior for each element and deducting it.

34. The method for examining the spectral content of an optical signal as claimed in Claim 32, wherein:

processing the element voltage by calculating channel power, signal to noise ratio and channel center wavelength.

35. The method for examining the spectral content of an optical signal as claimed in Claim 32, wherein:

processing the element voltage by converting the element voltage to element power.

36. The method for examining the spectral content of an optical signal as claimed in Claim 35, wherein:

calculating the channel power by summing the element power levels for at least one element for a given channel.

37. The method for examining the spectral content of an optical signal as claimed in Claim 36, wherein:

calculating signal to noise ratio by dividing the channel power by noise at channel boundaries.

38. The method for examining the spectral content of an optical signal as claimed in Claim 36, wherein:

calculating channel center wavelength using the element power for a given channel.

39. The method for examining the spectral content of an optical signal as claimed in Claim 38, wherein:

calculating channel center wavelength using second-order correction.

40. The method for examining the spectral content of an optical signal as claimed in Claim 28, wherein:

storing the output for future processing and performing a historical evaluation on the stored output.

41. A spectrograph for use in analyzing optical data signals, comprising:

a means for collimating an optical signal to produce a collimated beam, a means for directing the collimated beam onto a means for dispersing the collimated signal into dispersed channels, a means for directing the dispersed channels onto a means for focusing the dispersed channels across a linear detector array.

42. The spectrograph as claimed in Claim 41, wherein:

the dispersed channels include wavelengths of a telecommunication band.

43. The spectrograph as claimed in Claim 42, wherein:

the dispersed channels include wavelengths of 1300 nm to 1600 nm.

44. The spectrograph as claimed in Claim 41, wherein:

the means for collimating the signal includes a collimating lens.

45. The spectrograph as claimed in Claim 41, wherein:

the means for dispersing the collimated signal includes two gratings, wherein the means for directing the collimated signal directs the collimated signal onto a first grating to produce a dispersed beam, the first grating directs the dispersed beam onto the second grating to produce the dispersed channels, wherein the means for directing the dispersed channels directs the dispersed channels onto the means for focusing the dispersed channels .

46. The spectrograph as claimed in Claim 45, wherein:

a means for reducing polarization dependent losses is positioned between the first grating and the second grating, wherein the dispersed beam passes through the means for reducing polarization dependent losses before contacting the second grating.

47. The spectrograph as claimed in Claim 46, wherein:

the means for reducing polarization dependent losses includes a half-wave plate.

48. The spectrograph as claimed in Claim 41, wherein:

the dispersed channels are passed through a means for reducing polarization dependent losses.

49. The spectrograph as claimed in Claim 41, wherein:

the means for focusing the dispersed channels includes a focusing lens.

50. A spectrograph for use in analyzing optical data signals, comprising:

an optical signal directed through a collimator lens onto a grating which produces dispersed channels, the dispersed channels are dispersed across a linear detector array.

51. The spectrograph as claimed in Claim 50, wherein:

a half-wave plate is disposed between the grating and the linear detector array such that the polarization dependent losses are reduced.

52. The spectrograph as claimed in Claim 51, wherein:

a second grating is disposed between the half-wave plate and the linear detector array to generate the dispersed channels.

53. A method of calibrating an optical network monitor for monitoring optical signals, comprising:

measuring the dark current for elements of a linear detector array for a range of an integration time of interest;

modeling the dark current of the array elements of the linear detector array;

generating a calibration table of mapped element voltage and element sequence number to optical power and wavelength; and

downloading the modeling of the dark current and the calibration table to a memory to be accesses by a processor of the optical network monitor during the monitoring of an optical signal.

54. The method of calibrating an optical network monitor as claimed in Claim 53, wherein:

automatically creating the modeling of the dark current and the calibration table utilizing a computer program mechanism.

55. The method of calibrating an optical network monitor as claimed in Claim 51, wherein:

modeling the dark current for each element by a best-fit curve.

56. The method of calibrating an optical network monitor as claimed in Claim 53, wherein:

generating the calibration table by turning a light source across the elements; and

performing a comparison with a reference optical and wavelength meter.

57. The method of calibrating an optical network monitor as claimed in Claim 53, wherein:

generating the calibration table by turning a light source across the elements; and

performing a comparison with an optical network monitor.

58. A computer program product for automatically calibrating an optical network monitor for monitoring optical signals, the computer program product including a computer readable medium and a computer program mechanism stored thereon, the computer program mechanism comprising:

a calibration procedure configured to:

measure the dark current for elements of a linear detector array for a range of an integration time of interest;

model the dark current of the elements;

generate a calibration table of mapped element voltage and element sequence number to optical power and wavelength; and

download the model of the dark current and the calibration table to a

memory to be accesses by a processor of the optical network monitor during the monitoring of an optical signal.

59. A method of monitoring a communication network for the communication of optical signals at an intermediate node, comprising:

tapping into a communication network at an intermediate node;

receiving an optical signal from the communication network through a transceiver;

projecting the optical signal onto an spectrograph including gratings;

separating the optical signal into ranges of wavelengths across a detector array;

integrating the wavelengths on the detector array creating a element voltage for each element of the detector array;

converting the element voltage from an analog domain to a digital domain;

processing the element voltage through a processor utilizing internal algorithms;

generating an output of the optical signal's profile parameters;

communicating the output of the optical signal's profile parameters onto the communication network through the transceiver; and

controlling the receiving of signals or communicating the output onto the communication network through a site controller.

60. The method of monitoring a communication network as claimed in Claim 58, wherein:

controlling the site controller from a remote location to control the communication of the signal's profile parameters onto the communication network.

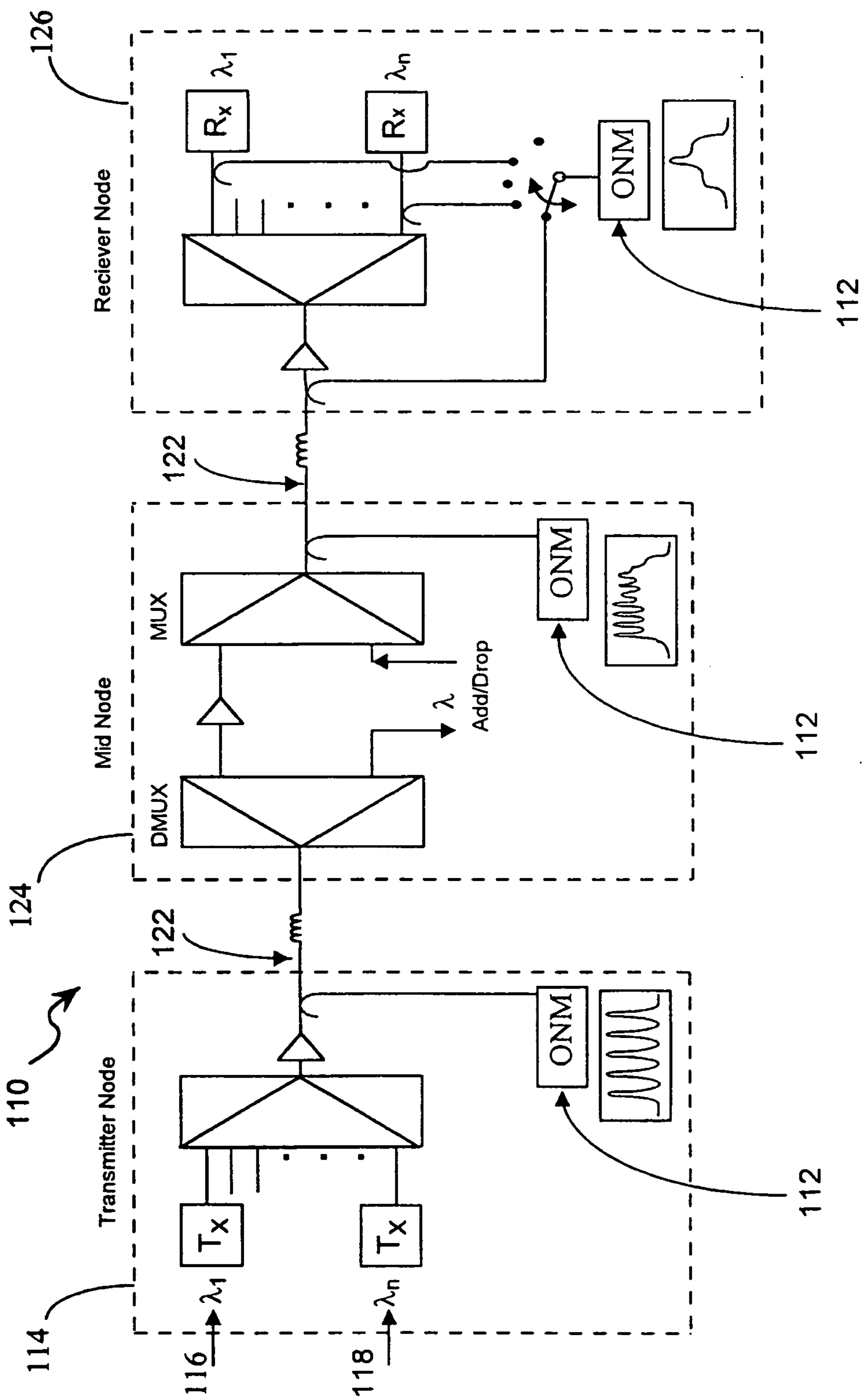

126
Reciever Node
R_x
λ_1
R_x
λ_n
ONM
112
122
Mid Node
MUX
DMUX
ONM
λ
Add/Drop
112
124
122
110
Transmitter Node
T_x
T_x
ONM
112
114
λ_1
λ_n
116
118

FIG. 1

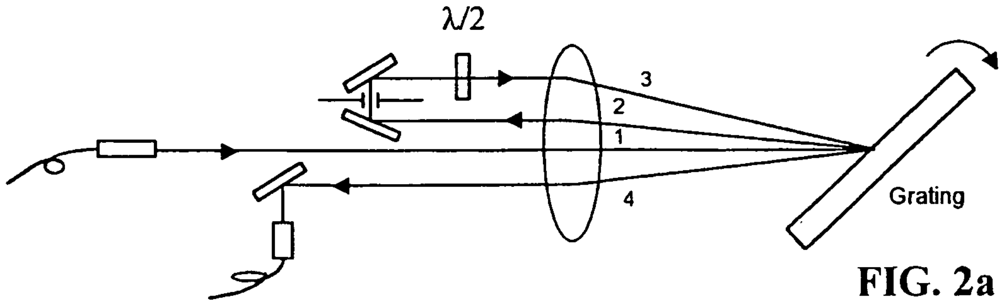


FIG. 2a

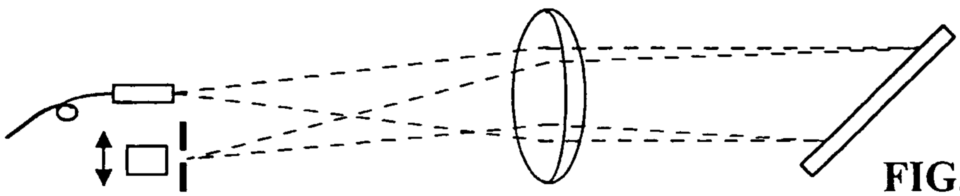


FIG. 2b

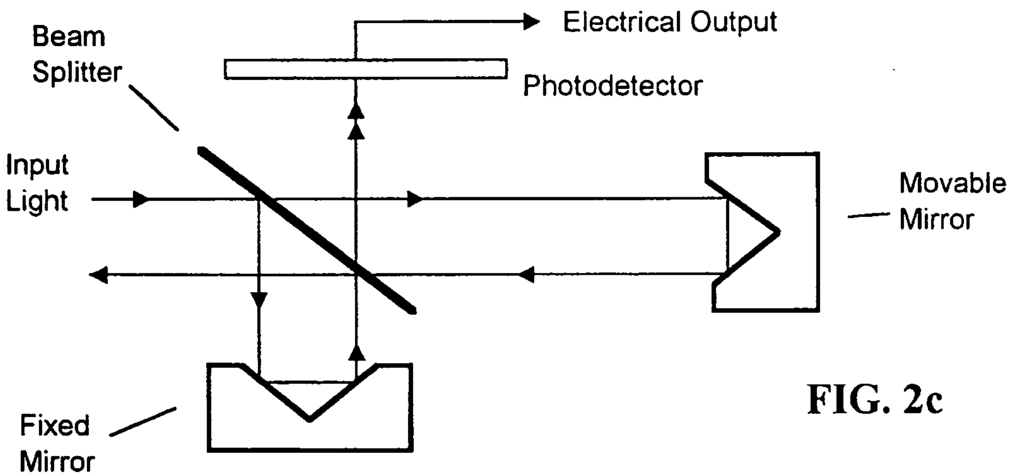


FIG. 2c

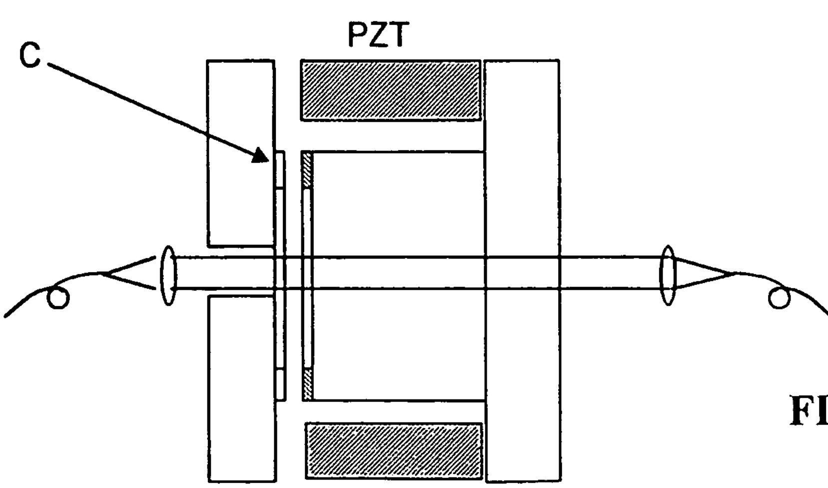


FIG. 2d

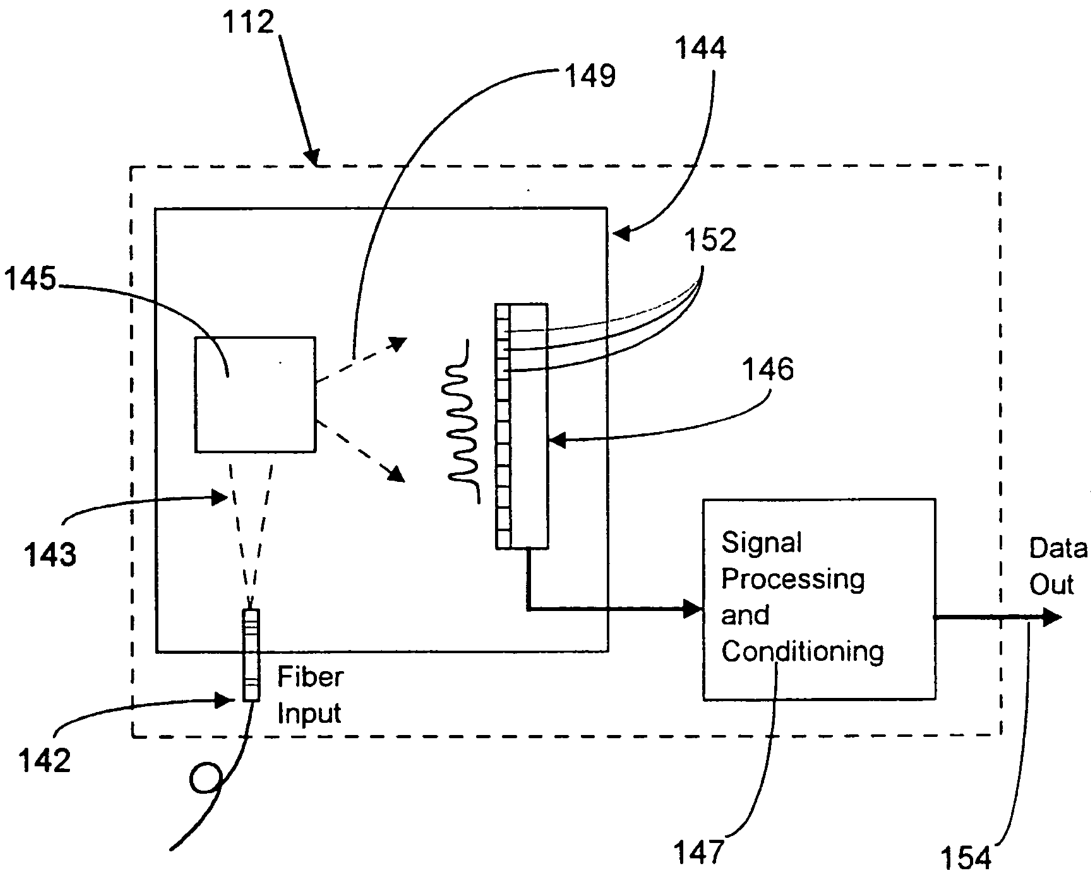

112
149
144
152
145
146
143
Signal Processing and Conditioning
Data Out
Fiber Input
142
147
154

FIG. 3

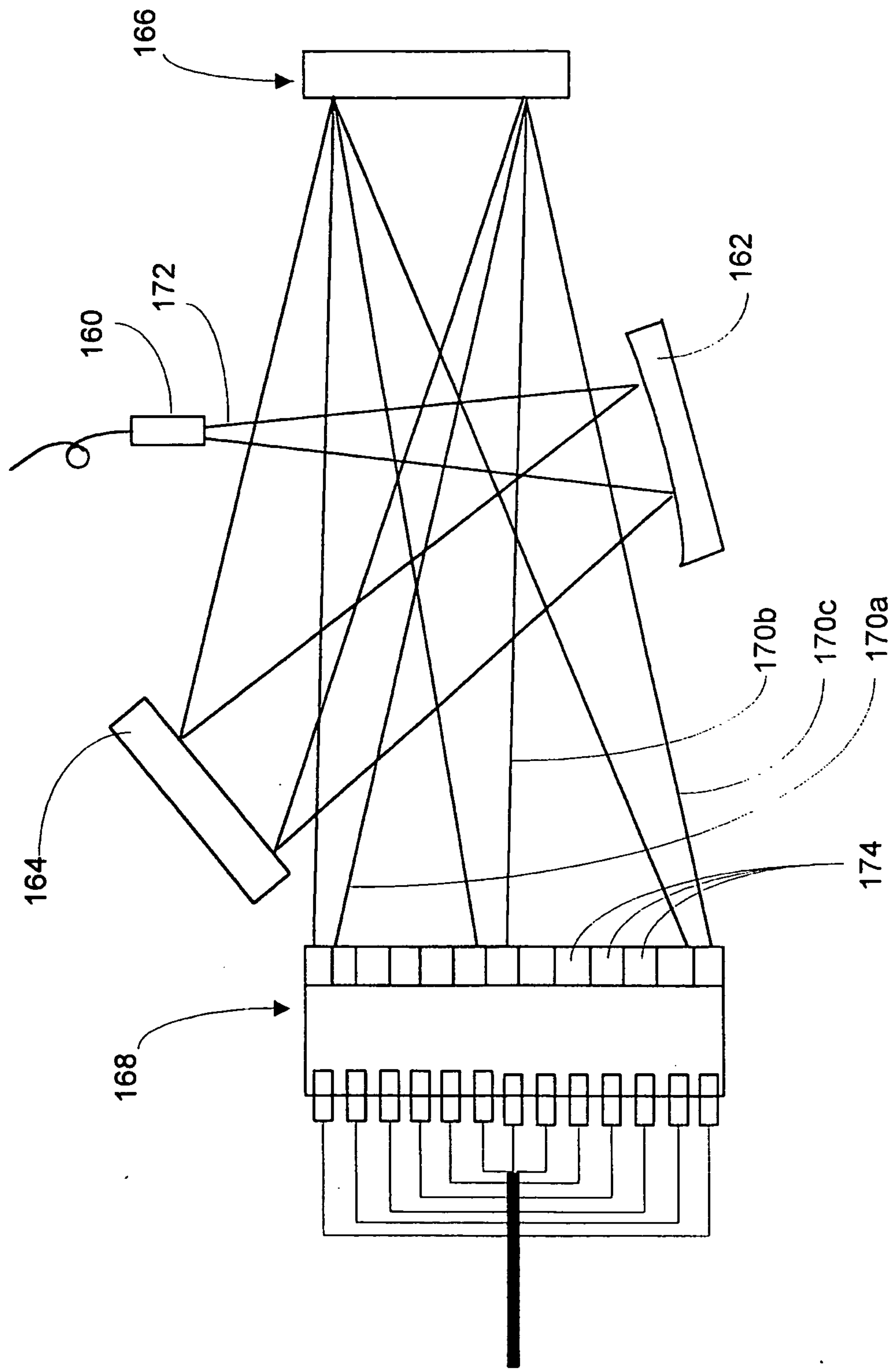


FIG. 4

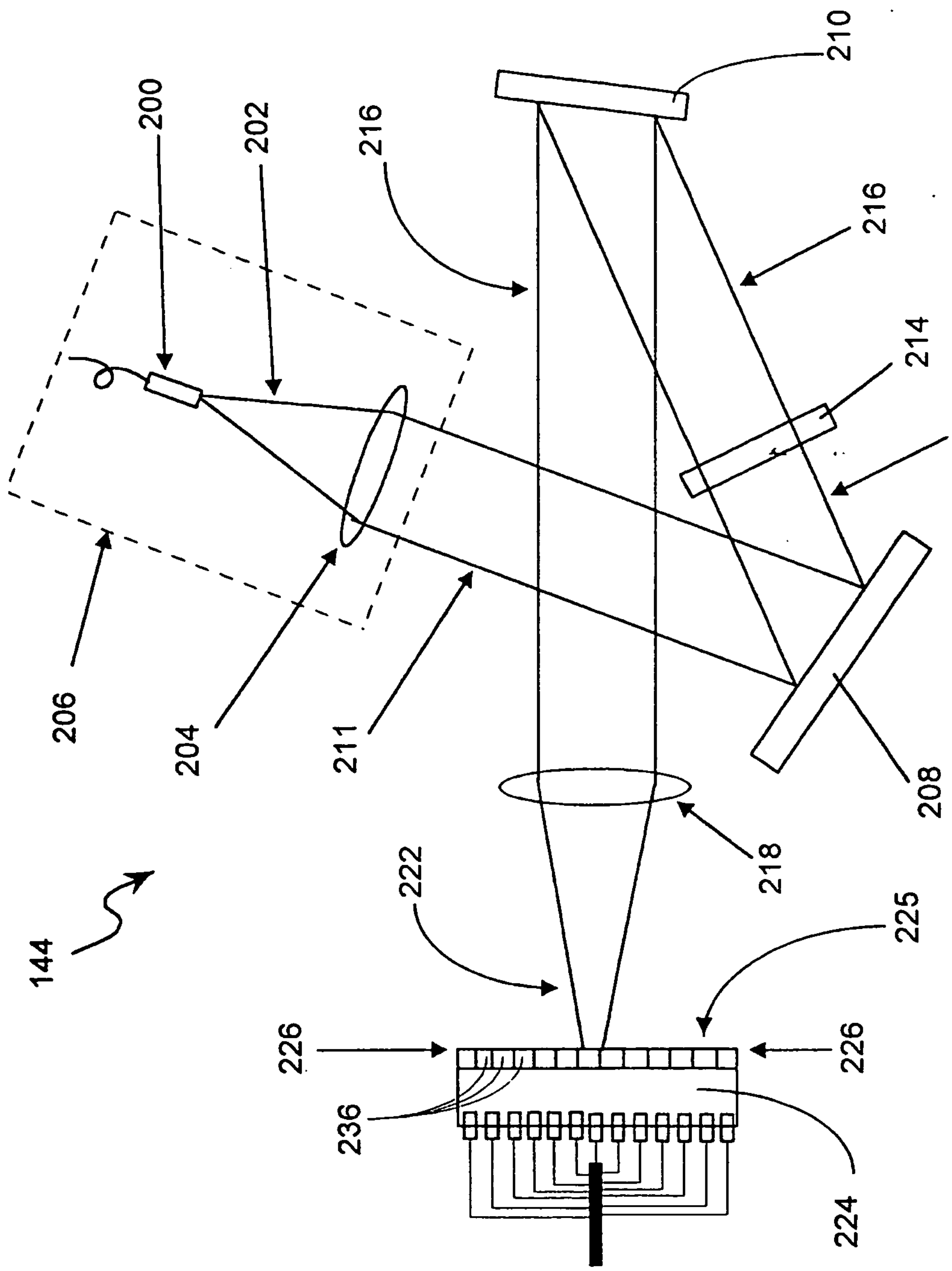

200
202
216
210
216
214
212
206
204
211
208
218
222
225
144
226
226
236
224

FIG. 5

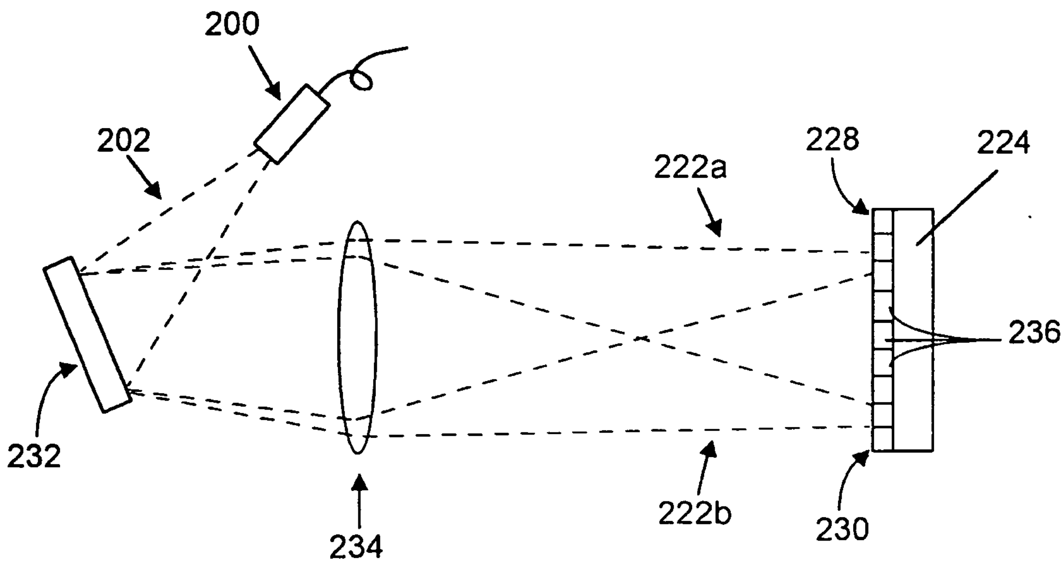


FIG. 6

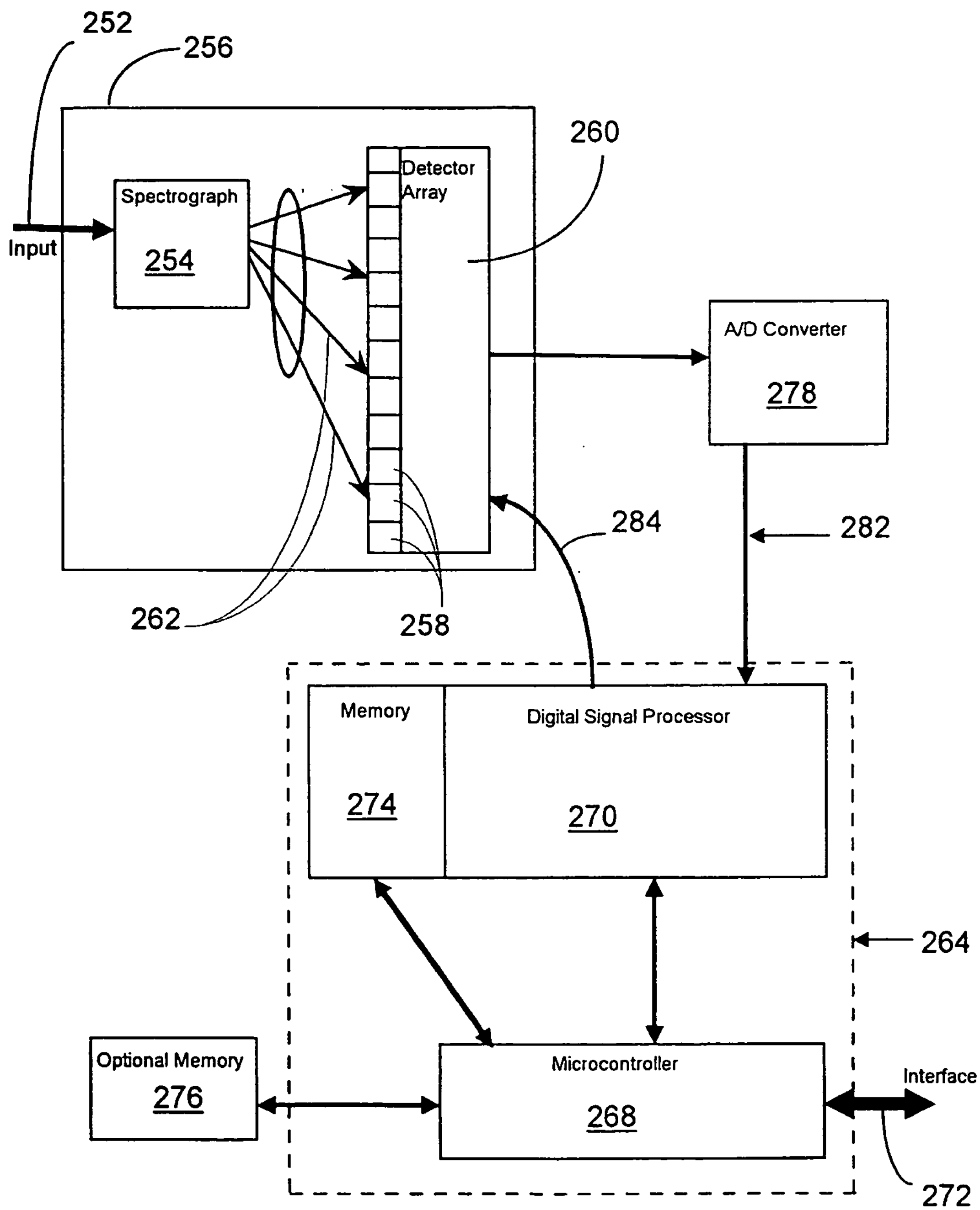
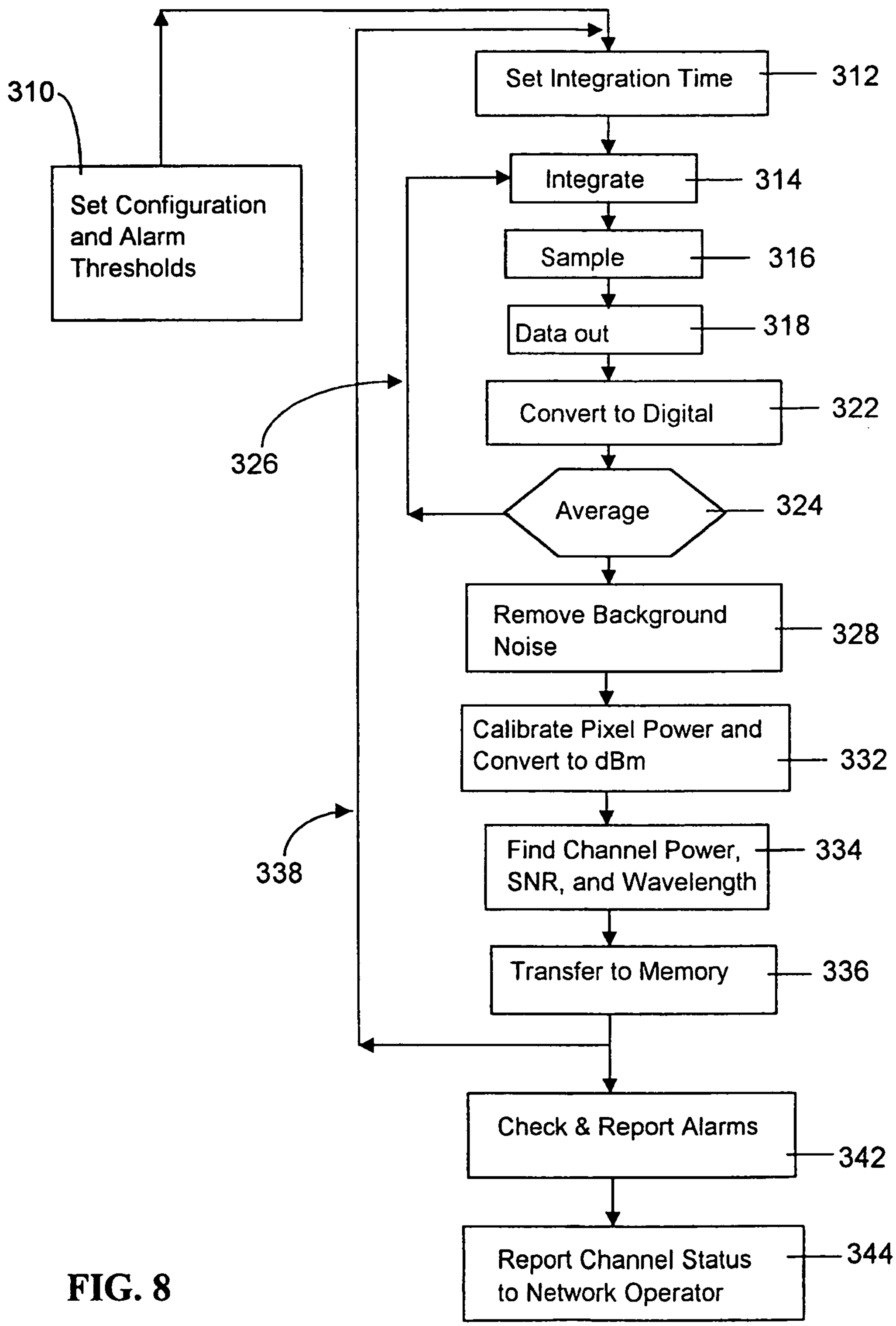

252
256
260
Input
Spectrograph
254
Detector
Array
A/D Converter
278
284
282
262
258
Memory
274
Digital Signal Processor
270
264
Optional Memory
276
Microcontroller
268
Interface
272

FIG. 7



Set Integration Time
312
310
Integrate
314
Set Configuration and Alarm Thresholds
Sample
316
Data out
318
Convert to Digital
322
326
Average
324
Remove Background Noise
328
Calibrate Pixel Power and Convert to dBm
332
338
Find Channel Power, SNR, and Wavelength
334
Transfer to Memory
336
Check & Report Alarms
342
Report Channel Status to Network Operator
344

FIG. 8

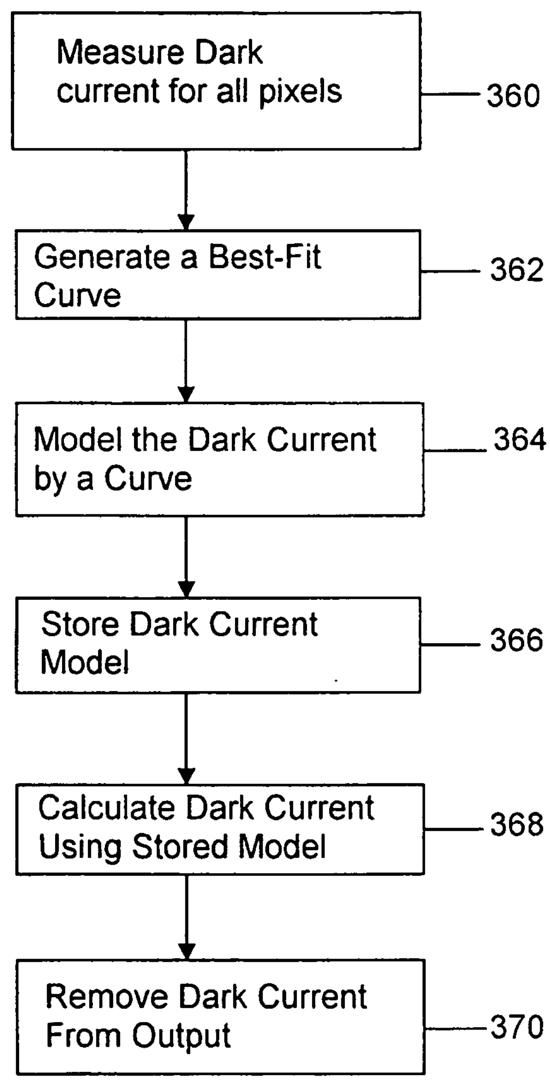

Measure Dark current for all pixels
360
Generate a Best-Fit Curve
362
Model the Dark Current by a Curve
364
Store Dark Current Model
366
Calculate Dark Current Using Stored Model
368
Remove Dark Current From Output
370

FIG. 9

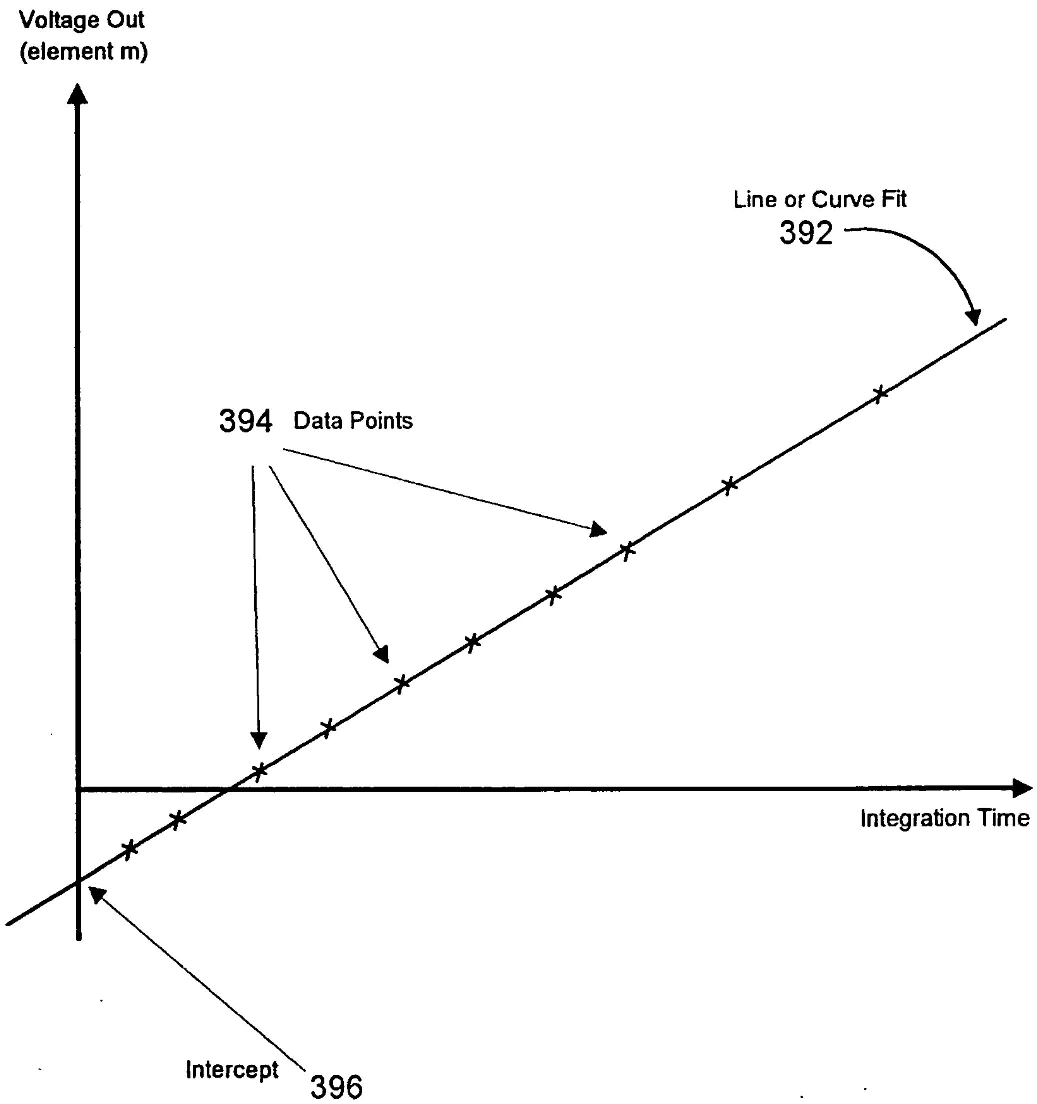

Voltage Out
(element m)
Line or Curve Fit
392
394 Data Points
Integration Time
Intercept
396

FIG. 10

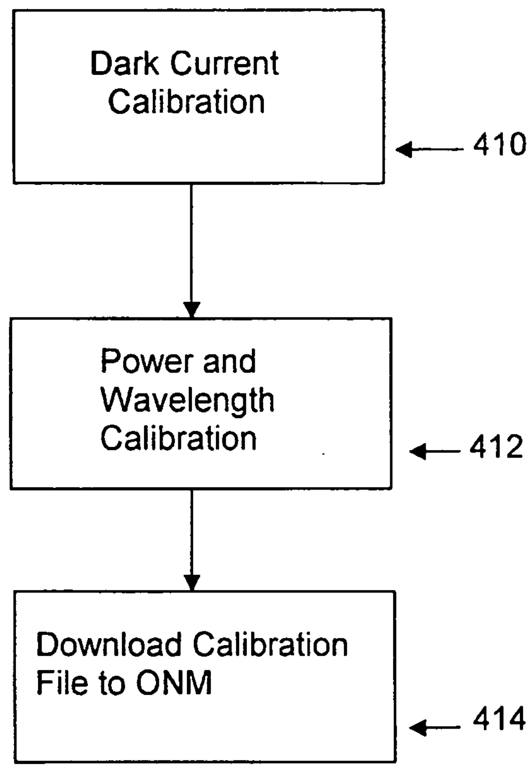

Dark Current Calibration
410
Power and Wavelength Calibration
412
Download Calibration File to ONM
414

FIG. 11

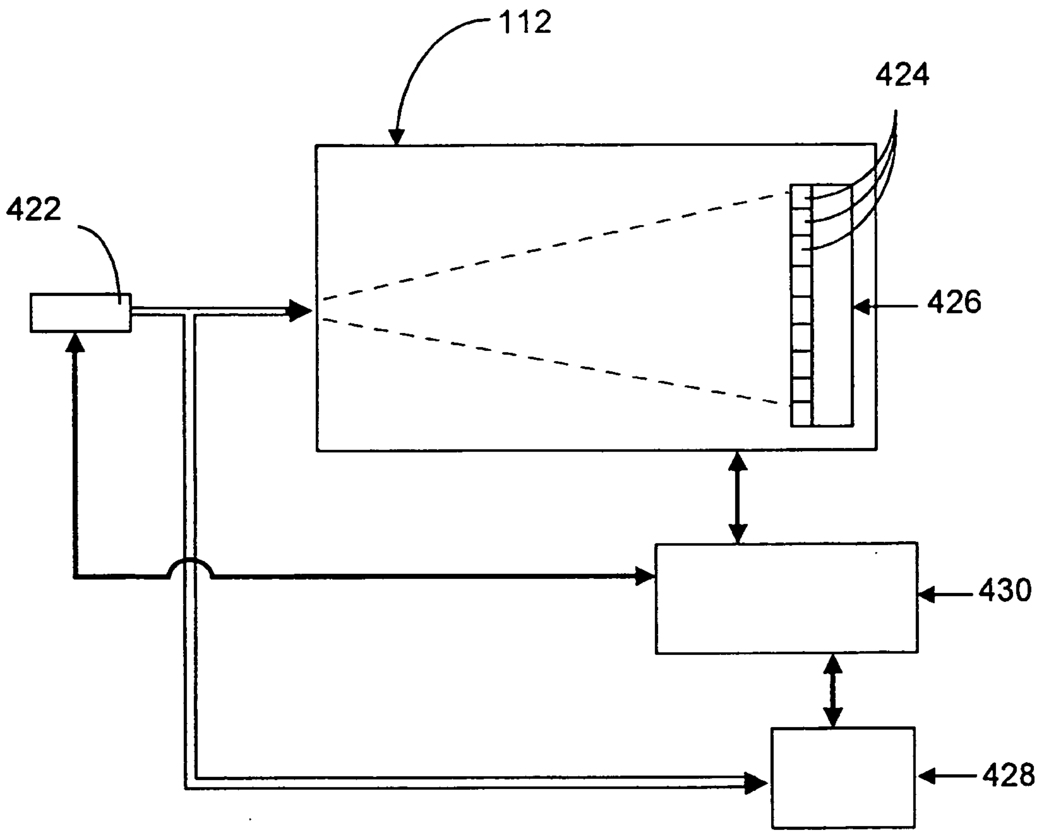


FIG. 12

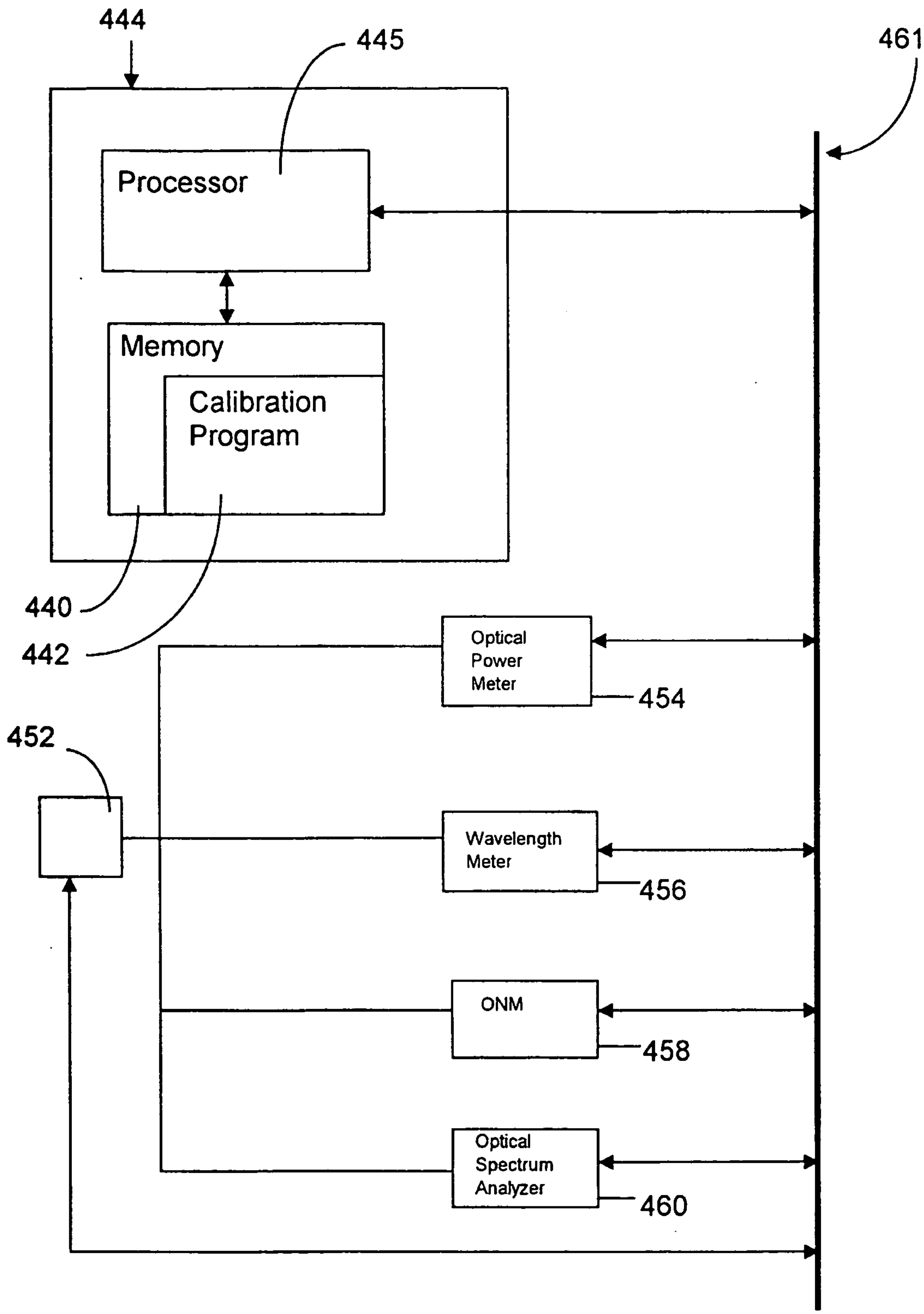

444
445
461
Processor
Memory
Calibration Program
440
442
Optical Power Meter
454
452
Wavelength Meter
456
ONM
458
Optical Spectrum Analyzer
460

FIG. 13

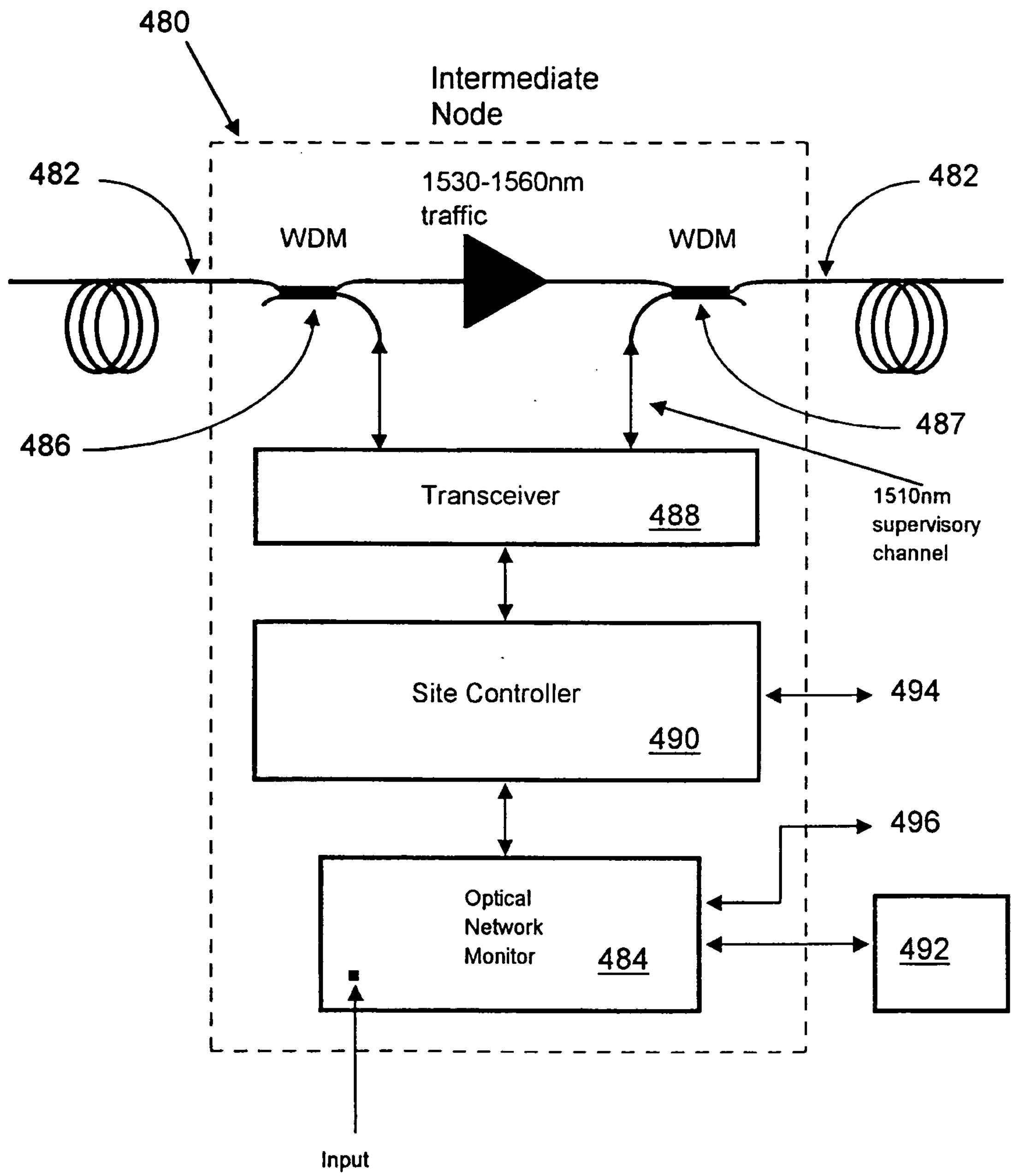

480
Intermediate
Node
482
1530-1560nm
traffic
482
WDM
WDM
486
487
Transceiver
488
1510nm
supervisory
channel
Site Controller
490
494
496
Optical
Network
Monitor
484
492
Input

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14301

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01J 3/18, 3/36; H04B 10/08; H04J 14/02
US CL :359/110, 127, 130, 161, 173; 356/305, 307, 319, 325, 328
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/110, 127, 130, 161, 173; 356/305, 307, 319, 325, 328

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 5,578,832 A (TRULSON et al) 26 November 1996, see column 18, lines 10-20; column 20, lines 5-22; column 21, lines 50-65.	1-5, 7, 13-18, 23-26, 28, 32-33, 41, 44, 48-50 ------- 8-12, 19-20, 25-26, 29-31, 40, 53-58
X -- Y	US 5,751,416 A (SINGH et al) 12 May 1998, column 6, line 58-column 7, line 14, column 9, lines 48-51; column 15, lines 1-8.	1-5, 7, 15, 18, 23-27, 41 ------ 8-12, 19-20, 29-31, 40

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 OCTOBER 1999	07 DEC 1999

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
LESLIE PASCAL Joni Hill
Telephone No. (703) 305-4700

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 5,489,980 A (ANTHONY) 06 February 1996, abstract column 5, lines 7-12, 35-37, 55-59; column 10, lines 35-column 11, line 63.	14 -------- 12, 25-26, 53-58
X -- Y	US 5,750,994 A (SCHLAGER) 12 May 1998, col 17, lines 50-column 18, line 3.	1-5, 7, 9, 16-18, 23-25, 41, 44 --- 32-33
X -- Y	US 5,141,609 A (SWEEDLER et al) 25 August 1992, figure 4.	1, 28-30, 41, 44, 49, 50 --- 32-33
X,E	US 5,930,015 A (YAMAMOTO et al) 27 July 1999, see figure 13.	1-6, 16-18, 20-23, 41-44, 50
X	US 5,541,756 A (CHANG-HASNAIN et al) 30 July 1996, column 1, lines 15-18; column 4, lines 64-67; column 3, lines 62-64.	1-4, 6, 17-18, 20, 23-24, 41-44, 50
X	US 4,742,577 A (VALDMANIS) 03 May 1988, figure 1 and column 3, lines 64-66; column 4, lines 42-44.	1, 6, 17, 18, 21-22, 41-44
A	US 4,191,473 A (HANSCH) 04 March 1980, abstract.	38-39

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/14301

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☒ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be searched, the appropriate additional search fees must be paid. The species are as follows:

1) figure 8 drawn to the conversion of element voltage into signals parameters.
2) figure 9 drawn to a flow diagram of the dark current and removing the dark current from the output.
3) figure 5 drawn to spectrograph with grating and half wave plate.
4) figure 14 drawn to a communication system.

The claims are deemed to correspond to the species listed above in the following manner:

1) claims 7-12, 14, 23-31, 35-40
2) claims 7-13, 28-34, 53-58
3) claims 45-48, 51-52
4) claims 59-60

The following claims are generic:

1-6, 15-22, 41-44, 49-50

The species listed above do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons: species 1 corresponds to the special feature of conversion of element voltage into signal parameters; species 2 is drawn to a device with special technical features that models and removes the dark current; species 3 has the special technical features of spectrograph with two gratings and half wave plate; species 4 is drawn to a communication system with the special technical feature of tap and a site controller.